Sleep Medicine 15 (2014) 1219–1224

Contents lists available at ScienceDirect

Sleep Medicine

journal homepage: www.elsevier.com/locate/sleep

Original Article

# Effects of different sleep deprivation protocols on sleep perception in healthy volunteers

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ARTICLE INFO

*Article history:*
Received 10 February 2014
Received in revised form 11 May 2014
Accepted 16 May 2014
Available online 30 June 2014

*Keywords:*
Total sleep deprivation
REM sleep
Sleep perception
Insomnia
Sleep deprivation
Sleep misperception

ABSTRACT

*Objectives:* To investigate whether different protocols of sleep deprivation modify sleep perception.
*Methods:* The effects of total sleep deprivation (TD) and selective rapid eye movement (REM) sleep deprivation (RD) on sleep perception were analyzed in normal volunteers. Thirty-one healthy males with normal sleep were randomized to one of three conditions: (i) normal uninterrupted sleep; (ii) four nights of RD; or (iii) two nights of TD. Morning perception of total sleep time was evaluated for each condition. Sleep perception was estimated using total sleep time (in hours) as perceived by the volunteer divided by the total sleep time (in hours) measured by polysomnography (PSG). The final value of this calculation was defined as the perception index (PI).
*Results:* There were no significant differences among the three groups of volunteers in the total sleep time measured by PSG or in the perception of total sleep time at baseline condition. Volunteers submitted to RD exhibited lower sleep PI scores as compared with controls during the sleep deprivation period ($P < 0.05$). Both RD and TD groups showed PI similar to controls during the recovery period.
*Conclusion:* Selective REM sleep deprivation reduced the ability of healthy young volunteers to perceive their total sleep time when compared with time measured by PSG. The data reinforce the influence of sleep deprivation on sleep perception.



## 1. Introduction

The factors that determine how an individual makes judgments about sleep continuity are the subject of speculation. That is, it is still not clear how an individual determines how long it takes to fall asleep, the frequency of awakening, the amount of time awake during the night of sleep, and how much sleep is obtained. It might be expected that a normal perception of sleep time would be the value that was closest to the objective evaluation. Nevertheless, when objective measures of sleep obtained by polysomnographic measures of sleep continuity are compared with their subjective equivalents, they are often discordant [1]. The reasons for this disparity involve the intrinsic mechanisms of perception of time during sleep that are related to the ability to subjectively estimate time-intervals and to differentiate states of consciousness (sleep and wakefulness).

When using two different methods for measuring the same variable, a certain degree of discordance may be expected. Here, discordance is even more likely since one measurement method is objective and the other is subjective. More specifically, polysomnography (PSG) is an 'online'/prospective evaluation of concrete data (rule-based judgments of a discrete representation of a biological state) in which assessments are made every 30 s. Conversely, there is also the subjective estimation of the total sleep time by the individual. This subjective perception can be understood as an 'offline'/retrospective evaluation, in which the data are based on memory for assessments of biological states in which the precision is unknown – thought to be ≥3 min [2]. In addition, several studies have clearly shown that good sleepers cannot recall information from periods immediately prior to sleep [3], during sleep [4–6], or from brief arousals which occur during the night [7,8].

Classical studies in healthy good sleepers suggest that some stages of sleep are more readily perceived as sleep whereas others are not: behavioral signaling and forced awakening studies, although providing variable outcomes for different stages of sleep, suggest uniformly that slow wave sleep is most readily perceived as sleep, followed by rapid eye movement (REM) sleep and then stage 2 [9–12]. More recent studies suggest that, in healthy good

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http://dx.doi.org/10.1016/j.sleep.2014.05.025
1389-9457/

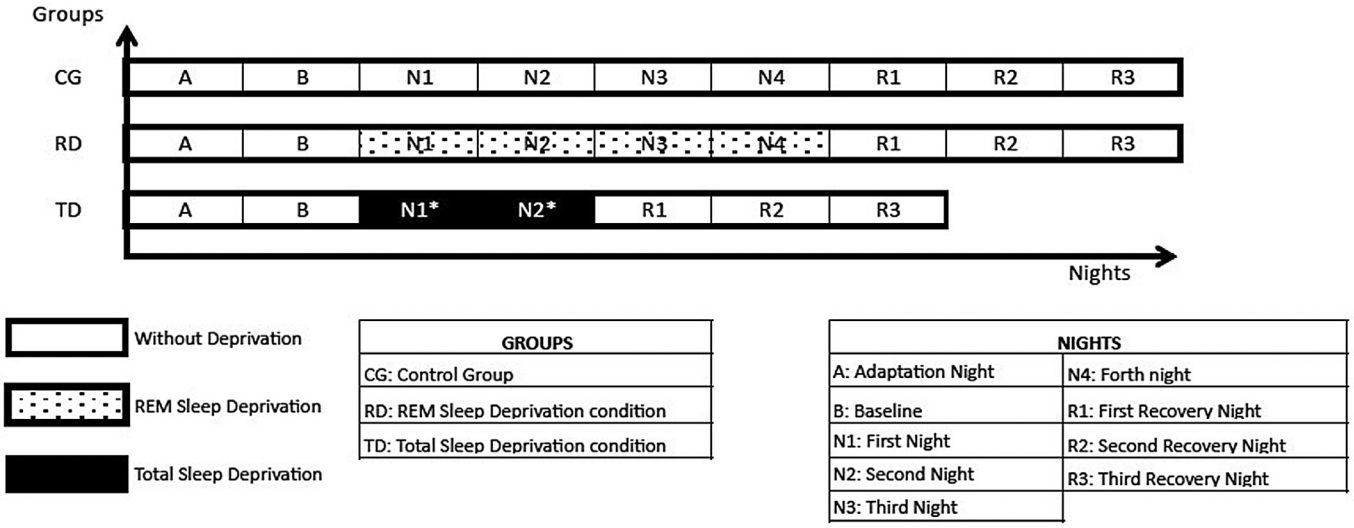


**Fig. 1.** Study design. All volunteers were evaluated daily by polysomnography (PSG) during the night and perception of total sleep time upon waking in the morning, except nights N1 and N2 for the total sleep deprivation (TD) condition. N1*/N2*, total sleep deprivation procedure for the TD condition; there was no PSG or evaluation of the perception of the total sleep time. REM, rapid eye movement sleep.

sleepers, the ability to estimate the passage of time during the night, in the absence of temporal clues, correlates positively with the percentage of slow wave sleep and negatively with the percentage of REM sleep [13,14].

To the best of our knowledge, no studies have been conducted on the effects of sleep restriction or sleep deprivation on the perception of sleep in healthy subjects. The aim of the present study was to analyze the effect of REM sleep deprivation (RD) and total sleep deprivation (TD) on the perception of total sleep time in healthy volunteers.

## 2. Methods

### 2.1. Study overview

The present study used data obtained from structured questionnaires and the same protocol of sleep deprivation utilized in a previous study, conducted at the Sleep Laboratory of the Departamento de Psicobiologia of the Universidade Federal de São Paulo. Details regarding the original investigation by Martins et al. have been published [15].

In brief, all volunteers underwent a rigorous screening protocol and, following the establishment of eligibility, spent seven to nine days in the laboratory (not including the screening PSG). All subjects were allowed to sleep from 23:00 to 08:00, except during the sleep deprivation nights. Day naps were not permitted. Behavioral stress and stressful exercise were avoided throughout the experimental protocol. The sequence of nights was as follows: adaptation, baseline, first to fourth nights (N1 to N4, respectively), and first to third recovery nights (R1 to R3, respectively).

In the control condition (first condition), subjects slept undisturbed for eight consecutive nights. Subjects allocated in the RD group (second condition) underwent four consecutive nights of REM sleep deprivation followed by three nights of recovery (undisturbed sleep). In the TD group (third condition), subjects underwent two consecutive nights of total sleep deprivation, totaling ~60 h of continuous wakefulness, followed by three nights of undisturbed sleep. All conditions entailed morning assessments of the volunteer's subjective impression of total sleep time. Figure 1 illustrates the study design.

### 2.2. Participants

Participants were recruited via e-mail, banners and personal contact from a pool of volunteers aged between 18 and 30 years. All participants signed the informed consent form. This study was approved by the institutional Ethics Committee (CEP/UNIFESP #1262/09).

The inclusion criteria were as follows: male gender, 18–30 years of age, education of ≥11 years (high school level or higher), normal sleep schedule/period, average sleep duration of 7–9 h, and normal scores on the Pittsburgh Sleep Quality Index [16], Epworth Sleepiness Scale [17], Beck Depression Inventory [18], and State-Trait Anxiety Inventory [18]. The parameters for normality on the aforementioned questionnaires were defined according to previously reported standards.

The exclusion criteria were as follows: history of neurological or psychiatric disorders, use of psychotropic medication, chemical dependence (alcohol, tobacco, or illicit drugs), presence of a sleep disturbance as assessed by clinical evaluation and/or PSG [19], shift work, extreme morningness-eveningness, organic disease, and/or any medical treatment known to affect sleep continuity, sleep architecture, and/or sleep perception.

### 2.3. Evaluation instruments and interventions

#### 2.3.1. Polysomnography (PSG)

As noted above, each participant stayed 7–9 h in the laboratory for PSG studies (not including the screening PSG). The first recording was used as an initial screening for occult sleep disorders, and the second as an adaptation night. Baseline measures were obtained in the third night of recording. The sleep deprivation conditions were applied in the following four nights (N1 to N4), followed by three nights of recovery (R1 to R3). In the RD group, subjects were submitted to REM sleep deprivation during the four recording nights (N1 to N4). The TD group underwent total sleep deprivation for two consecutive nights (N1 and N2). Finally, the control group had their sleep undisturbed.

All PSG were performed using Embla Digital A10 recording/amplifier polygraph and Somnologica software (Flaga h.f., Reykjavík, Iceland). Standard adult gold cup electrodes were used to record

electroencephalographic (EEG) signals (C3–A2, C4–A1, O1–A2, O2–A1) with EEG signals filtered at 0.3–70 Hz and sampled at 200 Hz with a 16-bit resolution. Recordings also included: (i) bilateral electro-oculograms (EOGs), (ii) electromyograms (EMG) of mentum and anterior tibial muscles, (iii) oro-nasal airflow (as measured by thermocouple and by a nasal cannula with a pressure transducer), (iv) respiratory effort (as measured by thoracic and abdominal piezoelectric belts), and (v) arterial oxygen saturation levels as assessed by pulse oximetry.

Sleep recordings were visually scored in 30 s epochs according to American Academy of Sleep Medicine standards for the scoring of sleep and associated events [20]. Respiratory events, periodic movements, and arousals were also assessed according to established criteria [20].

#### 2.3.2. Evaluation of sleep perception

Similar to the methodology used by Edinger et al [21]., sleep perception was evaluated using total sleep time (in hours) as perceived by the volunteer divided by the total sleep time (in hours) measured by PSG. The final value of this calculation was defined as the perception index (PI). The closer the PI is to 1, the more concordant the two estimates. Numbers < 1 indicate that subjective perception of total sleep time was less than the sleep amount measured by PSG. Numbers > 1 indicate that subjective perception of total sleep time was higher than the amount of sleep measured by PSG. As noted above, all subjective estimates were gathered in the morning following the PSG study (within 30 min of awakening). Volunteers had access to time cues before sleep onset, but not on awakening.

### 2.4. Sleep deprivation methods

#### 2.4.1. REM sleep deprivation (RD)

During RD nights (N1, N2, N3 and N4), REM sleep was detected by visual inspection of PSG. REM sleep was assessed in terms of: reduction of muscle tone on chin EMG, absence of spindles or K-complexes, tonic EEG pattern characterized by unsynchronized activity of mixed frequency with low amplitude (low or invariant amplitude), and presence of rapid eye movements [20]. When all these criteria were met, indicating REM sleep onset, the experimenters woke the individuals by speaking their name through an intercom [20]. In the event that the participant did not awake, the experimenters entered the room and manually awoke the volunteer. The volunteer was then kept awake for sufficient time to avoid an immediate relapse into REM sleep while keeping the waking episodes short enough to allow for frequent interventions. During the second half of the night, when the propensity for REM sleep was highest (return to REM sleep was inevitable), the volunteer was invited to get out of bed in order to remain awake.

#### 2.4.2. Total sleep deprivation (TD)

During the period of TD, participants were engaged in activities such as playing video games, watching television, and surfing the Internet. The experimenters, who ensured that sleep deprivation was maintained, continually monitored subjects allocated in this group.

### 2.5. Statistical analysis

Baseline parameters for volunteers in each condition (control, RD, and TD) were compared using one-way analysis of variance (ANOVA). Comparisons between two groups were performed using Student's *t*-test for independent samples.

Levene's test for homogeneity of variances was performed. When the supposition of homogeneity of variances was violated, degrees of freedom of *t*-test were calculated according to the Welch–Satterthwaite equation. To compare PSG parameters and sleep perception for a given group on the various nights of the experiment, ANOVA for repeated measures was used for each group. When significant differences were detected by ANOVA, a Bonferroni multiple comparisons test was used as post-hoc test. The comparison of variables within the same group on two different nights was performed using the paired Student's *t*-test. The data were also tested for homoscedasticity of variances by the Mauchly test. When the supposition of homoscedasticity was violated, the Greenhouse–Geisser correction was used. $P < 0.05$ was considered significant. Average values were described as average ± standard deviation.

## 3. Results

### 3.1. General characteristics

The experimental groups did not differ significantly regarding age [$F(2, 28) = 0.2$, $P = 0.823$] or body mass index (BMI) [$F(2, 28) = 0.30$, $P = 0.745$]. Average age was 22.5 ± 3.0 years and average BMI was 24.0 ± 2.0 kg/m$^2$.

### 3.2. Baseline characteristics of sleep parameters by condition

During baseline, significant differences were not detected among groups concerning the following parameters: total sleep time [$F(2, 28) = 2.20$, $P = 0.13$], percent time spent in stage 1 [$F(2, 28) = 1.97$, $P = 0.16$], percent time spent in stage 2 [$F(2, 28) = 0.09$, $P = 0.91$], slow wave sleep duration [$F(2, 28) = 0.07$, $P = 0.93$], percent time in REM sleep [$F(2,28) = 0.33$, $P = 0.72$], and sleep efficiency [$F(2, 28) = 0.81$, $P = 0.45$]. Furthermore, no significant differences were observed among groups regarding the perception index [$F(2, 27) = 0.34$, $P = 0.71$], indicating that sleep perception was similar in all conditions prior to sleep deprivation procedures.

### 3.3. Sleep patterns across the sleep deprivation procedures

As expected, no significant differences were detected for any of the PSG variables across the nine successive nights in the control group ($n = 10$).

In the RD group ($n = 12$), the percent REM sleep significantly decreased across the deprivation period (N1, N2, N3, and N4) when compared with the baseline night [$F(7.00, 45.45) = 126.78$, $P < 0.001$] and also when compared with the control condition on the same nights (N1 [$t(20) = 22.13$, $P < 0.001$], N2 [$t(20) = 17.54$, $P < 0.001$], N3 [$t(12.9) = 21.23$, $P < 0.001$] and N4 [$t(20) = 24.36$, $P < 0.001$]). During the recovery nights, the amount of REM sleep increased by 50% on the first night (R1) ($P = 0.03$) and returned to baseline values after one night of recovery sleep. Stage 1 sleep was increased across the RD period when compared with the baseline night [$F(3.24) = 15.55$, $P < 0.001$]. Sleep efficiency was reduced in three of the four nights of RD when compared with baseline values [$F(3.24) = 10.08$, $P < 0.001$], and, when compared with the control condition on the same nights, a significant reduction was observed on the following four nights of REM sleep deprivation: N1 [$t(20) = 2.67$, $P = 0.015$], N2 [$t(20) = 4.11$, $P = 0.001$], N3 [$t(20) = 4.46$, $P < 0.001$], and N4 [$t(20) = 6.26$, $P < 0.001$]. On the three recovery nights, sleep efficiency was increased when compared with the nights of RD [$F(3, 24) = 10.08$, $P < 0.001$]. When compared with the baseline night, total sleep time was only reduced on the last night of RD (N4), and it was increased on the first recovery night (R1) [$F(7, 70) = 26.37$, $P < 0.001$]. When compared with the control group on the same nights, the group that underwent selective RD showed a shorter total sleep time on the four nights of deprivation: N1 [$t(20) = 3.71$, $P = 0.001$], N2 [$t(20) = 8.35$, $P < 0.001$], N3 [$t(20) = 5.45$, $P < 0.001$] and N4 [$t(20) = 6.25$, $P < 0.001$]. The percentage of slow wave sleep was reduced when compared with the control group on nights N1 [$t(20) = 2.15$, $P = 0.04$] and N3 [$t(20) = 2.23$, $P = 0.03$].

**Table 1**
Perception index for all the nights of the protocol in the control, RD, and TD groups.

| | Baseline | N1 | N2 | N3 | N4 | R1 | R2 | R3 | *P'* |
|---|---|---|---|---|---|---|---|---|---|
| Control | 1.02 ± 0.25 | 1.03 ± 0.08 | 0.99 ± 0.08 | 1.00 ± 0.10 | 1.01 ± 0.08 | 1.09 ± 0.23 | 1.05 ± 0.13 | 1.03 ± 0.05 | 0.665 |
| RD | 0.98 ± 0.12 | 0.81 ± 0.22 | 0.85 ± 0.36 | 0.77 ± 0.30 | 0.77 ± 0.21 | 0.92 ± 0.12 | 0.97 ± 0.16 | 1.03 ± 0.11 | 0.309 |
| TD | 1.03 ± 0.07 | – | – | – | – | 0.90 ± 0.18 | 1.02 ± 0.10 | 1.05 ± 0.10 | 0.082 |
| *t* or *F*[a] | 0.34 | 3.10 | 1.23 | 2.41 | 3.52 | 3.14 | 0.91 | 0.17 | – |
| df | 2, 27 | 12.7 | 20.0 | 12.3 | 14.4 | 2, 27 | 2, 27 | 2, 24 | – |
| *P* | 0.715 | 0.009 | 0.234 | 0.032 | 0.003 | 0.060 | 0.414 | 0.844 | – |

*Abbreviations:* RD, rapid eye movement sleep deprivation during nights N1–N4; TD, total sleep deprivation for 48 h; df, degree of freedom with correction for homoscedasticity. Values are mean ± standard deviation.

[a] Comparisons between three groups were performed with analysis of variance for independent groups, and between two groups (nights N1–N4) with Student's *t*-test for independent samples.

In the TD condition ($n = 9$), REM sleep, slow wave sleep, and total sleep time rebounded following total sleep deprivation. The percent time of REM sleep for this group gradually increased across the three recovery nights, with the third recovery night (R3) being the greatest in relation to the baseline night [$F(3, 24) = 10.08$, $P < 0.001$]. When compared with the control condition on the first recovery night (R1), TD condition showed a higher percent time of REM sleep [$F(2, 27) = 11.55$, $P < 0.001$]. The amount of slow wave sleep was higher on the first recovery night (R1) compared with the baseline [$F(3, 24) = 4.23$, $P = 0.01$] and also when compared with the control condition on the same night [$F(2, 27) = 4.45$, $P = 0.02$]. The total sleep time was greater on the first recovery night (R1) in relation to the other nights in the same condition [$F(3, 24) = 43.32$, $P < 0.001$]. The total sleep time was also significantly higher in nights R1 and R2 when compared with the control condition [$F(2, 27) = 32.92$, $P < 0.001$; $F(2, 27) = 3.92$, $P = 0.032$, respectively]. Stage 1 was reduced in night R1 compared with the control condition on the same night ($F(2, 27) = 5.38$, $P = 0.011$). There was an increase in the sleep efficiency on nights R1 and R3 when compared with the night prior to sleep deprivation [$F(1.63, 13.05) = 17.81$, $P < 0.001$]; when compared with the control condition in the same nights, it was significantly higher in R1 [$F(2, 27) = 5.93$, $P = 0.007$].

### 3.4. Effects of sleep deprivation on the perception of total sleep time

The control and the RD groups did not show significant differences with respect to perception of total sleep time across the eight nights of the evaluation (baseline vs N1–N4, R1–R3). The TD group exhibited a non-significant trend toward the four nights evaluated such that R1 had a lower perception index than baseline, R2 and R3 [$F(3.21) = 2.56$, $P = 0.082$] (Table 1, Fig. 2).

The RD group exhibited significantly lower scores (perceived less total sleep time than measured by PSG) during N1, N3 and N4, when compared with the control groups on the same nights (Table 1, Fig. 2).

Additional data on PSG parameters are provided in Supplementary Table 1.

## 4. Discussion

The present study was undertaken to characterize the effects of sleep deprivation, both selective REM and total, on the perception of total sleep time in healthy, good sleeper subjects. Whereas volunteers submitted to REM sleep deprivation exhibited decreased perception of total sleep time during the sleep restriction protocol, total sleep deprivation did not lead to changes in sleep perception on the recovery nights.

With respect to RD, whereas it may be true that REM sleep state is sufficiently activated as to blur the perceptional line between wakefulness and sleep (and further that REM sleep may itself be positively correlated with wake after sleep onset time) [22], multiple forced awakenings during RD nights may have served to sensitize the subjects' perception of PSG-assessed wakefulness and thereby lead to decreased total sleep time estimates. Since good sleepers are not used to spending appreciable amounts of time awake during the night, this alone, or because enforced wakefulness was perceived as an aversive experience, led to a wakefulness overestimation. Frequent awakenings may have led to a shallower form of intermediary sleep (stage 2 or stage 1) with greater cortical activity related to stimulus/information processing. Further, the higher drive to REM sleep during RD could have altered the cholinergic tone, decreasing the physiologic mesograde amnesia of sleep and increasing the memory of wakefulness against sleep perception. The normal mesograde amnesia of sleep may be mediated by the lack of cholinergic neurotransmission during non-REM (NREM) sleep. If this were the case, then increased cholinergic neurotransmission during NREM sleep would be expected to lead to both sleep fragmentation and sleep misperception (because of augmented or slightly augmented memory for episodic events during the sleep

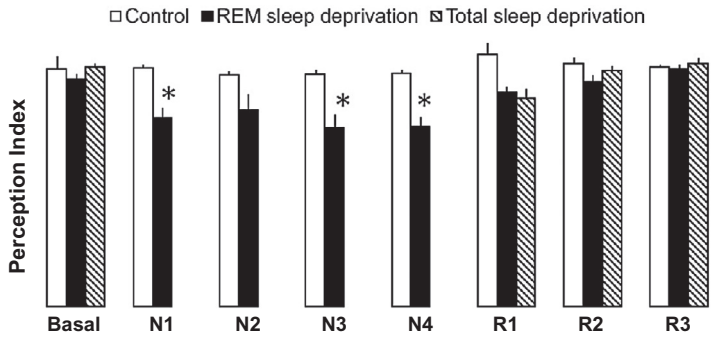


**Fig. 2.** Perception indices (PI; mean and standard deviation) for the control, rapid eye movement (REM) sleep deprivation and total sleep deprivation groups during the experimental nights (Basal, N1–N4, R1–R3). *PI significantly lower than for the control group on the same night (see Table 1 for *t*-values).

period). Thus, in the present study, selective REM sleep deprivation may have led to increased cholinergic neurotransmission during NREM sleep and thereby account for the observed increase in sleep state misperception.

One possible explanation could be the role of the hypothalamic–pituitary–adrenal axis (HPA) on stress mechanisms and on sleep perception, modulating the hyper-alert state in insomniacs, which has already been documented [23]. Backhaus et al. correlated HPA axis dysfunction with insomnia characterized by subjective sleep pattern alterations in the absence of significant correlations with PSG parameters [24]. Therefore, the effect of stress on sleep perception in this study could have HPA as an important neuroendocrine mechanism.

In addition to neurophysiological aspects that relate REM sleep to mental activity with a high level of information processing [25], evidence of the mechanism of some antidepressants show a link between REM sleep and mood modulation. Many antidepressants have their efficacy associated with the ability to suppress REM sleep [26,27]. In patients with depression and insomnia, those drugs often improve sleep complaints in addition to the mood [28]. Paradoxically, reducing REM sleep amount in asymptomatic individuals, in the present study, led to an underestimation of the subjective total sleep time compared to the PSG total sleep time. Feige et al. highlighted that in insomniacs with a decreased sleep perception, the time of perceived wakefulness after sleep onset was related to the amount of REM sleep [22]. Thus, the higher the percentage of REM sleep, the longer is the time of wakefulness during sleep as subjectively estimated. When comparing these data, a relationship is seen between sleep architecture, especially REM sleep, and the ability to perceive total sleep time.

With respect to total sleep deprivation, it is puzzling that this did not change the perceived total sleep time on the recovery nights, at least for R1. This is especially surprising given the effects observed with sleep restriction in patients with insomnia [29]. One interpretation is that there is a ceiling effect such that healthy good sleepers cannot perceive more sleep than is evident by PSG (i.e. are not subject to reverse sleep-state misperception). An alternative explanation may be that TD protocol was sufficiently stressful that it led to a level of central nervous system activation that offset the expected increase in sleep perception given a slow wave sleep rebound. The results described above provide evidence that the ability of healthy volunteers to perceive PSG total sleep time did not show statistical significant change after 48 h of TD. On the other hand, it is known that controlled partial sleep deprivation in patients with insomnia undergoing cognitive-behavioral therapy is an important therapeutic tool. Behavioral techniques that, directly or indirectly, use partial sleep deprivation result in improvement of the patient's symptoms towards sleep perception and quality of life. It is important to stress that whereas insomniacs have their sleep perception improved by partial sleep deprivation associated with the behavioral therapy, normal volunteers in this study were submitted to total sleep deprivation. As such, different types of sleep deprivation (total vs partial) can result in distinct effects on sleep perception. Recent data suggest that partial sleep deprivation in healthy individuals resulted in a subjective improvement in sleep quality [30]. Furthermore, increased sleep perception reported in insomniacs undergoing cognitive-behavioral therapy may be secondary to other aspects of the therapy, rather than the sleep deprivation itself.

In summary, our findings show that REM sleep deprivation leads to decreased perception of total sleep time in healthy volunteers, at least during the nights when sleep restriction occurs. Total sleep deprivation appears to have no effect on sleep perception. These data may be useful for better understanding of the mechanisms involved in sleep perception.

## Funding sources

This study was supported by grants from the Associação Fundo Incentivo à PESQUISA (AFIP) and the Fundação de Amparo a Pesquisa do Estado de São Paulo – FAPESP (CEPID #98/14303-3 to ST and 06/58276-8 to RCMS). Sergio Tufik and Monica Levy Andersen are the recipients of fellowship from the CNPq.

## Conflicts of interest

Dr Perlis has consulted for Gerson Lehrman Group, Clinical Advisors, MedaCorp./Leerink Swann, Actelion, SleepEasily, Sanofi-Aventis, and L.E.K. Consulting LLC. He has received research support from Sanofi-Aventis, Pharma, and Cephalon and has had speaking honoraria from Sanofi-Aventis, AASM, UR, and Internet Didactic Services. He has received salary and distributions from Actelion, Takeda, Gerson Lehman, Clinical Advisors, LEK, and MedaCorp.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: http://dx.doi.org/10.1016/j.sleep.2014.05.025.

## Appendix: Supplementary material

Supplementary data to this article can be found online at doi:10.1016/j.sleep.2014.05.025.

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